Towards standards for Pervasive Computing evaluation: using the multi-model and multi-agent paradigms for mobility

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Abstract. Pervasive Computing is about interconnected computing resources embedded in our daily lives and providing contextual services to users. One key element of the equation is "the human" and more specifically his behavior that is influenced and influences the environment. This article shows a generic way, using multi-agent systems (MAS) and multi-model paradigms, to evaluate communication related technologies based on a closed-loop between users and the pervasive computing environment. Our goal is to provide a framework where technologies could be evaluated and ideally certified "for a standard type of environment". First we present our generic framework for mobility modeling in dynamic networks and describe the design. We will describe its implementation and the experiments we have conducted in order to show its validity. Finally we argue that our framework could change how dynamic networks and more generally how behavior dependent technology will be evaluated in the future, which could lead to new standards.

Key words: Mobility, MANET, dynamic networks, agent, MAS, simulation, evaluation

1 Introduction

Pervasive Computing is about interconnected computing resources embedded in our daily lives and providing services to users in a changing context and environment. One key element of the equation is "the human" and more specifically his behavior. While user interfaces (UI) or interfaces in general take this into account, it is rarely the case in other domains when considering computing elements such as communication technologies (network, services). In the domain of dynamic networks, which will be our case study, Wireless technologies, ad hoc or mesh routing protocols, or ubiquitous services are often designed and evaluated using network simulators. As MANET real world experimentations with a representing set of devices is excessively time and money consuming, or even is scientifically of little relevance since reproducing a scenario / an experiment is not possible, network simulators are almost mandatory. Network simulators aimed at simulating the network layers in (more or less) details and indeed most of them are not designed for doing more, like advanced node dynamicity for example. In this paper we use MANETs (Mobile Ad hoc NETworks), as an example to demonstrate our approach. MANETs are wirelessly connected devices connecting spontaneously without any preexisting infrastructure. In MANET simulation, nodes move according to a mobility model. Most mobility models are calculated by merely considering the user as a random walker without goal or decision process, and without any knowledge of how the network actually behaves. Unfortunately this is what is generally considered sufficient to give the system its "dynamic" characteristic, and therefore is used to prove the validity and demonstrate the performance of protocols.

As a solution to fill this lack and go even further, we take advantage of research done in the multi-agent domain that focuses on behaviors of entities from a different point of view related to Pervasive Computing : human behavior is a corner-stone of any design and evaluation metric. We show a generic way, using multi-agent systems (MAS) and multi-model paradigms, to evaluate communication related technologies based on a closed-loop, interaction in both ways, between users and the pervasive computing environment. Our goal is to provide a framework where technologies could be evaluated and ideally certified "for a standard type of environment and context" (e.g. groups of users with given "standard" behaviors interacting with and within a "standard" set of changing environment).

The remainder of this paper is organized as follows. In Section 2, we present the Multi-Agent paradigm and the related work concerning MAS and existing mobility models used in simulators. Section 3 will give a detailed presentation of our solution which is based on multi-model, MAS and co-simulation. We will explain the concepts behind the modeling and implementation, as well as some experiments and their results that we've conducted as proves of concept. Section 4 will summary our contribution, ongoing and future work and try to emphasize our vision.

2 Simulations as evaluation tools : Agents and Mobility

2.1 Multi-Agent Paradigm

Multi-Agent paradigm is a way to model sets of autonomous entities interacting together with and within an environment. It is a well known paradigm used in Human sciences, Ecology or in Robotics. It describes the systems into (at least) these different components : agents, environment, interactions. The agents are autonomous and proactive entities, situated in an environment. They only have a partial (local) view of it and decide which action to take dealing with their own perceptions and reasoning.

MAS (Multi-Agent Simulation) or MABS (Multi-Agent Based Simulation) offers us the right level of description when we want to model users' behavior, goals and actions. Instead of using a global equation to model users' trajectories, we can, via the agent based model, re-create the way users move. It means that we can directly model behaviors such as "if an obstacle is present in front of you, then avoid it" or "reach a goal, stay nearby during five minutes and then go".

More generally, with this approach, we can model more complex behaviors such as willingness to use and share a service depending on the bandwidth consumed or the generosity of a user ; or the reaction to unpredictable events (as rain in the example scenario below, see **??**).

Mobility has already been studied and modeled via the multi-agent paradigm. Here agent can describe human, animal or robots. We can cite Craig Reynolds' work on bird flocks modeling where each agent try to keep inside the flocks only by computing a small set of forces (Boids [**?**]). Individual-based pedestrian modeling is also used in urban simulations (see the relevant works [**?**,**?**,**?**]). This paradigm is also used to model crowd scenes in movies (as battlefields in Lord of the Ring) and implemented in video animation software such as MASSIVE [**?**].

2.2 Mobility modeling: a quick survey

It seems important to point out that mobility models and mobility modeling are different but connected. There are many ways to model the different types of mobility.

Classical mobility models are well documented and can be classified as surveyed in [**?**] in 4 categories: random models (e.g. Random Waypoint), models with temporal (e.g. Gauss-Markov), spatial (e.g. Reference Point Group) or geographical (e.g. obstacle mobility) dependencies.

There is no formal model combining some of those classical models. And most critically, none ever considered any feedback (for example, closing the loop between the users and the underlying network behavior). Our work allows both by proposing to use the agent paradigm as a unique tool for modeling the largest and various sort of mobility.

3 Mobility modeling in MANETS: the case for multi-agent simulation

3.1 Usage scenario

To illustrate our approach lets consider a somehow typical usage scenario of MANETs. A user on a popular public place (e.g. a park) proposes a service, for example an Internet connection sharing, that is distributed and shared via an ad hoc network. People that have a wireless capable device, discover this useful service in an automated way (e.g. using a service discovery protocol). They start to use this service, and probably most of them stay more or less nearby it. As the service becomes more popular and the neighboring user population is growing, the ad hoc network becomes denser and the service reaches more and more users. The presence of an interesting and working service at a particular location changes the user's behavior. Here typically, people try to stay nearby the service. We see that the network influences the user's behavior.

Imagine, the weather is getting bad and it starts to rain. Most of the users will probably search for a dry place, and the underlying network topology will stretch, probably to the point of failure for most of the nodes if there is not enough volunteers to get soaked by maintaining the service reachability. This behavior affects the network topology and its performance. Here the user's behavior influences the network. (Other problems related to users' behavior could also occur : for example, generally speaking, if the density of user increases too much, the network and/or service performances will decrease).

With this simple scenario we observe that network performance (... QoS) does not only depend on hardware, software or protocol properties, the human or sociologic aspects also need to be considered.

3.2 User model description

Our agent based mobility model is inspired from urban research and pedestrian modeling [**?**,**?**], but could be extended by other models. Each mobile node (a user) is represented by an agent (named a_i). The agent behavior is modeled as a function, a sum of forces, resulting in our example in a node movement (later on, network interaction will be considered). More generally it can be seen as a combination of simple behaviors resulting in a complex one. Each force/behavior describes an interaction of the agent with its environment and the other agents. The agent has a limited perception: these interactions are effective only on the neighborhood of the agent. In our case, the movements of the agents are computed by applying laws of mechanics: namely point kinematics. This kind of models is easily extensible (adding a new interaction corresponds to adding a new force), easy to implement and can express a large set of behaviors by weighting each force. The example below explains a simple model of behavior: the agents avoid obstacles and have goals.

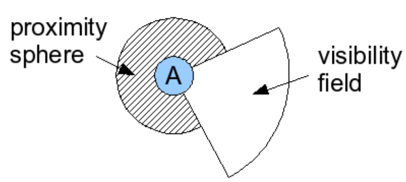

Fig. 1. An agent based model of a mobile node (a user)

Fig. 2. Repulsive force for obstacle avoidance model

Obstacle avoidance behavior: When an obstacle (see **??**, e.g. agent or wall) is present either in the proximity sphere or in the visibility field of the agent (see **??**), we compute a force which value is given by the equation below where δ is the euclidian distance to the obstacle, v is the unit vector Obstacle to Agent and α and β are tunable parameters. $\overrightarrow{F}=\overrightarrow{v}\ .\alpha/(\delta)^{\beta}$

Goal oriented behavior: Our agents are attracted by their goals. They are not moving randomly but towards a given goal g_i. For g_i, we compute a force for the agent until it reaches a "satisfaction" condition (in our example a satisfaction zone, see figure **??**).

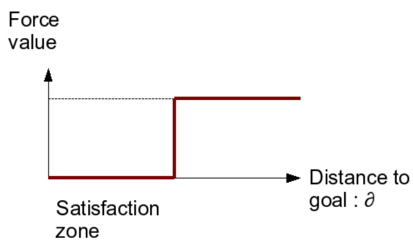

Fig. 3. Attractive force to the goal

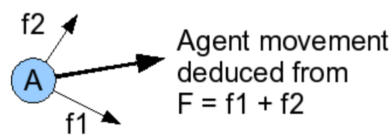

Fig. 4. Movement computation

Movement computation: The decision process of our agents results in a movement. Each force is weighted. This weight is a tunable value that represents the importance of the interaction in the behavior. This way, with our two simple behaviors, we have a complete range of scenarios and outcomes, going from pure obstacle avoidance to pure goal attraction just by modifying the wheights. The agent resulting behavior is formulated as $\overrightarrow{F}= \sum w_i \times\ \overrightarrow{f_i}$ (see figure **??**). The acceleration $\overrightarrow{ac}$ is computed by the following equation $\overrightarrow{ac}=\overrightarrow{F}\ /m$. The speed is updated as follow $\overrightarrow{v}\leftarrow\overrightarrow{v}\ + \overrightarrow{ac}$. The speed is limited by an upper bound.

3.3 Synthesis

This model respects the constraints cited in [**?**]: temporal dependency, spatial dependency and geographical depedency are achieved according to the weights on forces.

Describing sophisticated movements is straightforward: for example from our two simple movements we have nodes avoiding obstacles and following multiple succeeding goals. Moreover, we can easily model mobility of groups of people just by adding a force that attracts agents that go in the same direction (as in flocking models, see [**?**]).

Since this modeling approach is individual-based, we can easily describe heterogeneity of behaviors. Indeed, the highest level of granularity can be reached by implementing a different model of behavior per agent. Thus, we can describe, for example, different kind and mixes of populations. Finally, with our approach, a user can dynamically switch from one behavior to another.

3.4 Design and implementation

The design is inspired by HLA (High Level Architecture) which main goal is reusability and interoperability of different simulators. As in HLA, our framework aims at using existing simulators (or other entities e.g. visualization systems) and combine their specialization. As consequence, it provides a multi-model simulation and evaluation environment where every part does only what it was designed for. The first advantage of this approach is that people can remain specialist of their own specific domain. For example radio propagation specialist do not need to know how the network simulator is implemented and do not even need to know which network simulator will be used, but can develop and test his ideas not only in terms of radio-wave propagation properties, but also in terms of usability with different routing protocols or even more with real-life scenarios. Another advantage is that replacing a simulator does not require major changes on the existing architecture. The design of our framework is shown on figure **??**. The link between the differents simulator is done by a a synchronization and messaging service. At first we simplified the design of our implementation by using a combination of the JANE[**?**] (Java Ad Hoc simulator) Network Simulator and our own Multi-Agent Simulator. JANE is used as the synchronization entity for practical reasons although we've had to solve the time-representation discrepancy between both tools (time and step-based).

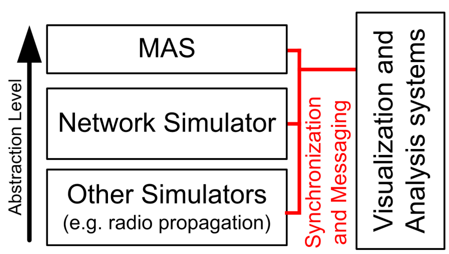

Fig. 5. Framework design

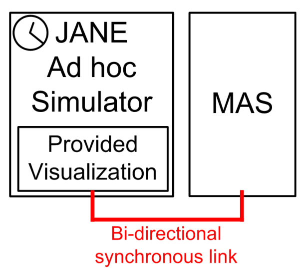

Fig. 6. Framework implementation

Performance Using agents to simulate basic behaviors such as random waypoints seems probably overkill at first, but once it has been implemented, variables can be easily adjusted and for performance reasons we provide a "scripted mobility service": when there is no interaction between users and "the pervasive computing environment", our engine can just pre-compute the movements which can be injected into a network simulator. This is a compute once, use many times approach, that can be extended and made interactive with our agent-based modeling.

From simple new mobility models Typical scenarios and simulation, are shown in figure **??** where the advanced mobility model is used in different environments (Corridor, Crossroads, Walls and Museum) using the routing protocol OLSR. User 1 announces a service that interests the other users that are trying to keep this service within network reachability. Once this goal is achieved, they remain still (not moving) until they lose the service. Those scenarios where there is no interaction would be possible to evaluate using current mobility models and simulators but they would require much more development time and be less flexible than what is possible with our MAS-based approach.

In figures 8,9,10 we show our advanced mobility model with feedback, consisting in connectivity and hop count to the service in the same environment at different point of time. It gives classical network related information. In this case it shows the variations of hop counts. The fluctuation is strongly dependent on the parameters for the mobility models.

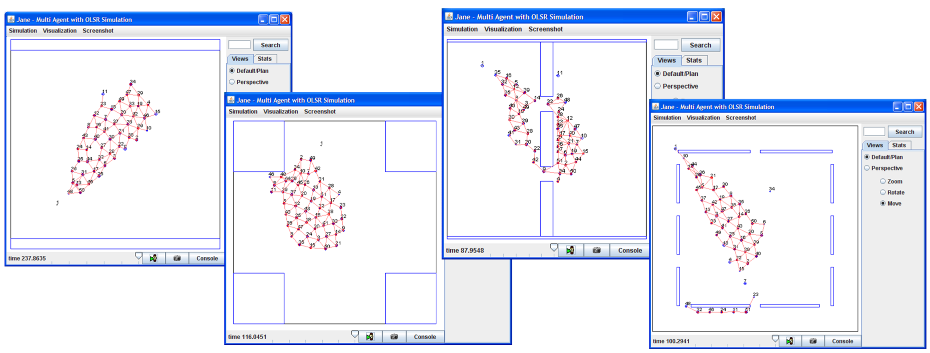

Fig. 7. Same mobility model, multiple environments

...To new functionalities and standards A very simple scenario, where network performances modify the user's behavior (like our park example) is not feasible with more classical approaches. Now we can imagine new scenarios where today's mobility models can not be used as-is. In a middle-term, it is reasonable to present a set of mobility models, a set of environments and their combination that would be both virtualized (modeled and simulated) and have a real setup (a typical existing room or building or city modeled in 3D for example). They would serve as references that could be used to evaluate the performances and applicability of a solution, and validate it in certain contexts, thus providing the pervasive computing community with a standardized evaluation toolkit.

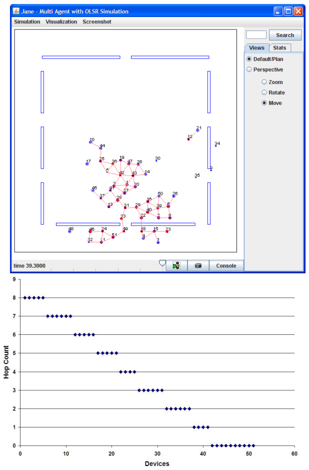

Fig. 8. t=39 s

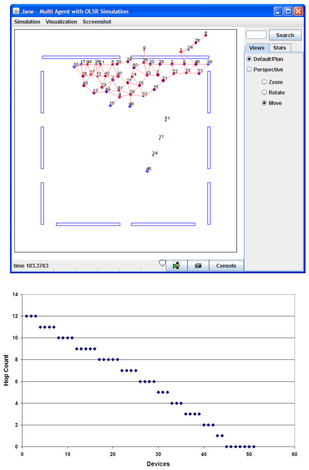

Fig. 9. t=183 s

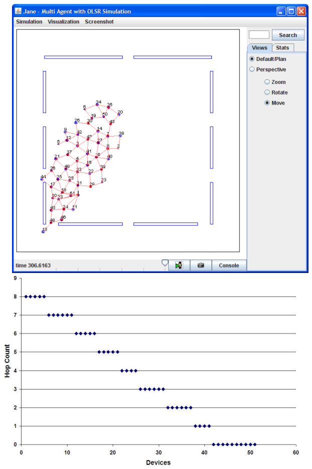

Fig. 10. t=306 s

4 Conclusion

In this article, we have presented a conceptual framework and a prototype implementation for mobility modeling which is a key point in evaluating wireless technologies and services, and a couple of experiments we have conducted on our framework. We've argued and shown in our prototype its main properties, which are :

– The Multi-Model approach is a separation of concern (and problems) approach
– The Multi-Agent Simulation allows even non specialists to scientifically implement and validate their solutions, and the low-levels designers to give "real-life" example for their technology or protocols
– While it still provides the usual mobility models, it is very simple to design, fine-tune, redesign those models or even design new ones.
– The new mobility models can take into account networks or more generally environment inputs, basically having a closed-loop system where something closer to the "human behavior and real-life" is considered.

Therefore, our approach offers a basis for valid comparison of wireless technologies and services but it can be extended to any dynamic environment, such as P2P networks for example, and it is very well-suited every situation where there are interactions between the users and the (networking) environment.

4.1 Ongoing and future work

As our work is partially integrated within the French National Research Agency (ANR) project SARAH (Services Avancés pour réseaux ad hoc / Advanced Services for Ad hoc Network), we will have the opportunity deploy and test our solution in real-life but controlled scenarios in the "Cité des Télécoms (Telecommunication City) in Brittany, France. This is a museum already equipped with wireless networks and applications that is used as a "standard" test environment for our advanced ad hoc services, and that is being modeled in our simulation environment. Hence, we will have the opportunity to hopefully validate our approach

Our platform will be extended by defining and implementing more standard and novel mobility models (node/users behaviors), and reference environments and we are currently working on a multi-model formalism that will be the basis for our simulation framework.

4.2 Final words

This article shows a generic way, using multi-agent simulation (MAS) and multi-model paradigms, to evaluate communication related technologies based on a closed-loop between users and the pervasive computing environment. Our goal is to provide a framework where technologies could be evaluated and ideally certified "for a standard type of environment". This would give the ability for a technology designer to say: "my service, my device, my protocol will or wont' work in those environments with those type of users". About a specific routing protocol, its designer could still satisfy his scientific colleagues with: "it works well with high density, low mobility scenarios", but he could also add: "it works well in downtown scenarios at rush hour, but not in a shopping mall on saturday afternoon" and we believe that is what makes all the difference.

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